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ABSTRACT

Presented is a study of a science program for upper elementary and middle school children encouraging the development of logical thinking skills, describing variables, interpreting and criticizing experiments, and understanding exp[illegible]iment design. To provide a basis for the program, the students suggested projects to be done and developed activities to correspond. Two fifth-grade classes served as the trial group and two as controls. Comparison of composite scores on the California test of Basic Skills showed comparable ability levels [illegible] the two groups. Three forms of a Science Process Test (SPT) to measure student achievement were devised. It was concluded that the personalized program was especially effective for low achievement students. Observations during the program revealed that the social structure of the classroom, and the fact that most rewards in the usual classroom came from the teacher, influenced the behavior of the students. It was also indicated that classes unaccustomed to working alone find the transition from group to personalized work difficult. (Authors/EB)

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PERSONALIZATION IN SCIENCE: A PILOT STUDY[1]

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Introduction

Current theories of instruction emphasize that learning is most likely to take place when students are interested in what they are investigating and when the learning task is challenging but not frustrating (Bruner, 1960). One way to increase student interest and provide challenging situations is to encourage the student to select his learning task as well as the equipment he needs to accomplish it. Programs that reflect these ideas are often called "personalized," "individualized," "independent," or "open." In this research we have developed a personalized program for beginning science and determined some of the advantages and disadvantages of such a program.

A review of available individualized elementary science programs revealed that most American programs involve either changes in classroom organization (e.g., team teaching, multi-age grouping) or changes in curriculum presentation (e.g., programmed texts, contracts). Novak (1972) has summarized currently available individualized programs as follows: "In general, students in a given subject area (physics, biology) receive the same curriculum (the same concepts are

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taught) but instruction is arranged to allow individual students to proceed at their own rate, and to some extent with differing instructional content." One example of a change in curriculum presentation is the Science Curriculum for Individualized Learning (SCIL) which is an individualized version of the Science Curriculum Improvement Study (SCIS) (Appel, undated; Appel & Conard, 1972).

At this time it appears that most individualized programs have been based on previously established curriculum content. Attempts to choose new concepts particularly suited to individualized approaches in laboratory-oriented science at the elementary level have not been frequent. One program which does attempt this is the Individualized Science (IS) program. This is a multimedia program which is being developed without reliance on any available program. Cassette tapes and kits of materials are used. The activities a child can initially choose from are determined by his pretest score. Future activity choices are determined by scores on the follow up test for his first activity. At certain points convergent activities are assigned to individuals to teach a particular concept (Klopfer, 1971). This program is, thus, quite structured.

Another trend in individualizing science instruction by developing new curriculum content is found in England. The Nuffield Junior Science Program is based on the premise that all children will not profit from the same experiences (Nuffield Junior Science, 1967). A teacher's guide explains the program but equipment is not provided because it is considered restricting. The role of the teacher in this program is described as follows (Nuffield Junior Science 1967, p. 46): "It is impossible and undersirable to stipulate a set syllabus....every child will be at a different stage of development....

and have his own particular interests. The teacher's first duty is to present the child with a range of materials." "Once the children are interested in and handling things it is imperative for the teacher to discuss (their work) with them."

Clearly the Nuffield Junior Science program is quite unstructured. Even in English schools with their history of "open" education, the adoption of the program has been somewhat limited. The freedom for the children suggested by the Nuffield project, and the lack of provided materials, seems to be confusing to many teachers.

The Science 5/13 project, (1972) which evolved out of the work of the Nuffield Junior Science Project, has tried to structure science experiences by developing many activities to accomplish the same goals. Activities are organized around specific topics (wood, color, etc.). Lists of needed materials are provided. Science 5/13 is oriented to small groups, since several students usually study a given unit at the same time. Several units may be used simultaneously in the same classroom.

Examples in the teacher's guides for both the English programs indicate that for some students these projects are very successful in teaching both content and experimentation. Clearly these programs, since they give suggestions rather than directions to the teachers, are extremely teacher dependent. Goals for the programs are presently quite general--specifics are left up to the teacher. Also, the source of equipment is sometimes a problem for the teachers.

Results from the English programs, as well as research on aptitude-treatment-interactions (Cronbach & Snow, 1969; Cronbach & Snow, in preparation), and our own experience with group-oriented laboratory

programs, have provided stimulation for two major ideas which form the basis for our personalized program: (1) All children will not profit from the same activities; (2) Children can select activities on their own that will be intellectually meaningful to them.

We are developing a personalized science program for upper elementary and middle school children. The purpose of this program is to encourage the development of these logical thinking skills: recognizing and describing variables, interpreting and criticizing experiments, and understanding experimental design. Thus, our program is not based on a currently available curriculum. We have chosen this goal rather than a more content-oriented goal because we think a personalized program is particularly well suited to teaching these aspects of logical thinking and because we feel there are many experiential group-oriented programs that successfully teach basic ideas of elementary science.

Personalization seems to be a suitable approach for teaching logical thinking for several reasons. One is that there are large individual differences in logical thinking (Piaget, 1952; Inhelder & Piaget, 1958). Piaget has observed that children progress through qualitatively different stages in logical thinking and that they may be at one level for one task and at another level on another task. From Piaget's work it is also clear that most upper elementary age children are quite concrete in their logical thinking and thus more likely to learn from concrete experiences than from abstract descriptions of experiences. A personalized program is more likely to respond to individual differences than a group program.

Research has shown that logical thinking can be fostered by certain concrete experiential procedures. Research on the effectiveness of the Science Curriculum Improvement Study, an equipment-centered, group-oriented

elementary science program has shown that these concrete expriences result in better logical thinking skills (Linn & Peterson, 1973; Linn & Thier, in press). Anderson (1969) has shown that individual training with equipment is successful for teaching bright first graders a concept identification task. Kohnstamm (1962) has shown that young children can learn a class inclusion problem after extensive individual training with concrete materials. Fischbein, Pampu, and Manzat (1970) used an individual training procedure to teach the concept of chance to young children. Case (in press) has shown that third graders with high Block Design scores can be individually trained with a special apparatus to control variables. Beilen (1971) summarized studies of training in logical thinking and concluded that success is possible although the long term effects are not known. This research indicates that a personalized program which provides concrete experiences for children and allows for individual differences by letting students to choose their own projects is likely to foster logical thinking at least in some children.

Thus, the objectives of the present study were: (1) To develop a personalized program in trial form which allows children to choose their own projects and to work individually with equipment; (2) To observe what happens when such a program is introduced in an American classroom; (3) To determine whether the program fosters logical thinking in children; (4) To look for indications that individual differences in initial ability might interact with success in the program.

The Teaching Program

The personalized program was developed using two fifth-grade classes in an upper middle class school. An introduction to science concepts and use of materials preceeded the program.

Introduction to Experimentation

While a totally personalized program affords an excellent opportunity for children to work at their own level with equipment, it depends on some student initiative and skill with equipment. Students in the present study had been in a traditional book-oriented science program and had no experience working with equipment. It was felt that their first exposure to equipment should be somewhat guided.

One equipment-centered science program, Science Curriculum Improvement Study (SCIS), provides an ordered introduction to concepts important for scientific investigation, thereby paving the way for students to design experiments of their own. Using the SCIS framework of exploration, invention, and discovery, the concepts of object, property, evidence, system, interaction, variable, and histogram from Material Objects (1970), Interaction and Systems (1970), and Subsystems and Variables (1970) were introduced. Equipment (but not concepts) from upper-grade units (Energy Sources, 1971; Models 1971) was used to make the instruction appropriate for these fifth-grade children. The teaching sequence was selected by the project staff to emphasize using equipment, carrying out experiments, recording data, and describing results.

The Personalized Program

To provide basis for the personalized program, we decided to ask students to suggest projects that they would like to do and then to develop activities to match each student suggestion. In our program each child worked on his own activity until he decided he had completed it. Then he made a written report of what he had done and selected a new activity. Students were encouraged to develop their own format for making reports. There was no restriction on what activity could be chosen, although the type of equipment was negotiated with the leader.

There was also no restriction on how many students chose the same activity, as long as they worked on it by themselves.

Two fifth-grade classes who served as the trial group for this project were asked to list between one and three experiments that they would like to do. They were told that they would soon be able to work on projects they were interested in, by themselves.

Of the fifty-three pupils in the two classes, forty-nine listed between zero and four activities and four pupils were absent. An average of two activities was requested by each child. The activities listed and the frequency with which they occurred are given in Table 1. Opposite the student requests are the projects we designed to match the request. Suggestions by students turned out to be very general. For example, students frequently said they wanted to work with "chemicals." Many students also expressed an interest in power or energy. We developed four activities in this area: (1) Making electric circuits using batteries, bulbs, and motors; (2) Making an electromagnet; (3) Designing a magnetic oscillator; (4) Experimenting with the effects of different variables on magnetic attraction (Magnetic Quadrant). The table shows that although many children were interested in life science projects, problems of maintaining organisms in the classroom could not readily be handled by a staff who visited the classroom only twice a week. Therefore, only physical science projects were provided. All students had suggested at least one physical science project, so no problems with pupil interest were anticipated.

These projects were assembled and a "Project Preview" was organized, where the materials for each project were gathered and demonstrated at tables in a multipurpose room by ten members of the Lawrence Hall of Science staff. Students circulated around the room and decided which

project they were interested in. They were told that if they did not see something that interested them they could request something else and it would be obtained if possible. The Remote Airplane, Oil Spill, and Hot Wheels and Motors projects were provided as a result of special requests.

After the students chose their first project, they were given their materials, asked to write down what they intended to do, and interviewed by a member of the project staff. The interviewer asked the student what variables he planned to investigate and how he planned to conduct his experiments. If necessary, he helped the student plan his first experiment.

The program then began in the classroom. Twice a week for nine weeks the students spent an hour on their projects. They wrote reports when they finished an activity and then selected another one. They were encouraged to suggest their own activities and were told that we would attempt to get any additional equipment that they needed for activities they were doing.

Each project session was supervised by an experienced laboratory science teacher who was a former member of the SCIS project development staff. At least one other staff member from our project was present during each class session. This person (or persons) assisted with distribution and collection of materials, recorded his observations, answered pupils' questions, and, at times, even intiated small group discussions. The staff answered fact-oriented questions as well as they could. When asked a general question, staff members attempted to help by asking the student more about his request. Thus, when asked "What experiment should I do next?" staff members said "What would you like to find out?" or "What have you found?" Specific suggestions

were not given. Three staff members were usually present and busy during the personalized program. Both professional and financial inputs to this program during its operation were at least three times what one normally finds in the classroom. The regular classroom teacher was present but took no part in the program.

Procedure

Subjects

Four fifth-grade classes in an upper middle class suburban school participated in this study. Two classes received the teaching program and two served as controls. Comparison of composite scores on the California Test of Basic Skills (given before the teaching program was begun) for children in the two groups indicated that ability levels were equal (experimental mean = 187.6, standard deviation = 41.0; control mean = 191.8, standard deviation = 32.7). These children had not used any experiential or materials-centered science program in the past. Science had been taught in the "traditional" manner from a textbook, augmented by experiences devised by individual teachers.

Evaluation of Logical Thinking Skills

The program was designed to promote logical thinking, especially in the areas of interpreting and designing experiments and describing variables. The evaluation described below was designed to assess these goals.

Group Measure. Three forms of a Science Process Test (SPT) to measure student understanding of variables and ability to interpret and design experiments were devised. One form of the SPT is shown in Figure 2. In each form of SPT the questions followed the same format

but materials from different mechanical systems were used. Commercial "hot wheels" cars and adjustable ramps were used for SPT Form 1. SPT Form 2 was done with spheres which rolled down a ramp and hit a target. SPT Form 3 used "Stopper Poppers" from the SCIS Energy Sources (1971) unit. These are syringes with corks instead of needles. By pushing the plunger the cork is released.

Form 3 of the SPT is shown in Figure 2. This test will be described in detail. The others were very similar. The mechanical system, Stopper Popper, was set up in two ways such that four variables were different in the two experiments. The four variables for stopper popper were: (1) angle of release, (2) location of system (desk or floor), (3) distance of plunger from syringe, (4) degree to which stopper is pushed into socket. These differences were also diagrammed, as shown in Part I of Figure 2. The experimenter described the two stopper popper set ups, passed out paper for Part I of the SPT, explained the diagrams on the test sheets and read the question, asking the students to describe the variables in the stopper popper system. These papers were collected.

The system was then dismantled and the experimenter demonstrated how a weight could be attached to the stopper. She passed out papers that asked the students to diagram and describe an experiment which would show the effect the weight has on how far the stopper goes (Figure 2, Part II). Then she set up an experiment in which she changed how far the plunger was from the stopper as diagrammed on the test sheet. The students were asked to tell whether or not this was a good experiment to investigate the effect of the distance of the plunger. Actually it was not, because one system was on the floor, and the other on the desk (Figure 2, Part III). Students marked "yes" or "no" and then explained

their answers. The next questions were similar but asked about the degree to which the stopper was pushed into the syringe and the angle the stopper was released from. The last question asked the student to explain the result of an experiment where variables compensated for each other.

The SPT questions were scored as follows. On Part I, Variables, a score of 1 to 3 was assigned to each variable mentioned. These numbers were then summed to get a variables score. One point was given for variables named in the course of describing the experiment (e.g., "The high stopper will go further than low"). Two points were given for naming whatever was varied (e.g., plunger). Three points were given for describing how the variables could be changed (e.g., the distance the plunger is pushed into the syringe).

Scores for Part II of the SPT reflected the number of variables (except weight) that were controlled. Thus, 0 = no experiment, 1 = only one trial, 2 = some variables controlled, 3 = all but one variable controlled, 4 = all variables controlled. On Part III of the SPT, questions 1 and 2 were scored as correct if the student recognized the uncontrolled variable, and question 3 was scored correct if the student noted that the variable under investigation was not manipulated. Question 4 asked the student to explain a situation using compensating variables. In conjunction with SPT 3, an additional task on compensation was also used. This was the Cart Experiment developed by Linn & Thier (in press). This task, presented on 16mm silent film, shows a cart going down a ramp from a high or low position on a soft or a hard surface. Both compensating variables tasks were scored as follows: 0 = wrong or no answer; 1 = some mention of variables (e.g., "High goes faster");

2 = mention of one variable, implicit mention of the other (e.g., "It comes out even because surface slows it down"); 3 = mention of two variables using "but" or "and" to describe compensation (e.g., "One starts high but surface slows it down, other starts low but has smooth surface").

Interviews. Two forms of controlling variables tasks from Piaget's work which have been standardized by Case (in press), were used as another measure of controlling variables. One is called Spinning Wheels, the other Bending Rods. These are individual interviews lasting about fifteeen minutes each. One form of this task (Spinning Wheels) was given after the experimental subjects had completed the Introduction to Experimentation, the other (Bending Rods) was given after the subjects completed the personalized part of the program. All interviews were carried out by the same person. Scores on this test range from 0 to 5 depending on the number of variables that the subject controls.

Design

All group evaluation measures were administered by the same experimenter. Form 1 of the SPT was administered before teaching began. Then the Introduction to Experimentation was taught to the experimental classes. Control classes had the regular book-oriented science program. After the Introduction, Form 2 of the SPT was administered to all classes. At this point, the Spinning Wheels interview was given to one experimental class and one control class. The other two classes were not tested due to time considerations. Classes to receive the interview were randomly selected. The personalized teaching program was then carried out for nine weeks. Form 3 of the SPT with the Cart Experiment was administered to all classes after the personalized program. All subjects were also given the Bending Rods interview after the teaching program was completed.

From the group measures, a variables score and an experiment score were determined for each student at three points: (1) before the program began, (2) after the Introduction to Experimentation, (3) after the personalized program. The variables score was the score on SPT Part I. The experiment score was the sum of scores on SPT Parts II and III and on the Cart experiment.

Results and Discussion

Student Response to Introduction to Experimentation

Students, in general, expressed great interest in equipment, a high level of motivation, and a high level of cooperation during the SCIS-based Introduction to Experimentation. This response is the usual response of an upper middle class student population using SCIS for the first time.

Student Response to the Personalized Program

Whereas the response to the group teaching was as expected, the personalized program yielded a number of interesting observations.

Activities chosen. After the project preview described previously, many students wanted to work with Thermicon cards. These had been used in the introduction to experimentation and were very intriguing. Thus, each child was given one to take home to do their own experiments. At this point the experimenters assumed that students all wanted these cards because they had recently worked with them. Later, it was recognized that this was one example of peer influence. Those who listed Thermicon cards as their first choice were given their second choice. Of the remaining projects presented at the project preview, ten were selected by at least one student and three special projects were requested, as shown in Table 1.

After the initial presentation of the projects, a sheet of small pictures showing each project was posted to help students remember which projects were available. Students were also encouraged to come up with additional suggestions and told that every effort would be made to get materials for them. Three additional special requests were filled after the personalized program began.

Table 2 shows the number of students who used each project during the nine-week personalized program. Eleven of the seventeen initial projects were tried at least once, and six special requests were filled during the personalized program. The most striking fact, as shown in Table 2, is that a small number of activities were used by many students. The Acid-Base activity was used by thirty-six students, Airplanes by twenty-three, and Candles by twenty. Although many choices were available and students were encouraged to come up with new ideas, the students tended to each choose the same projects.

Students frequently consulted each other about what experiments to do next, how many reports they should write, how to use the materials they had chosen, etc. The same few students generally initiated new activities. Other students tended to request the activities initiated by these few. At any one class meeting, the majority of students was working on two or three projects. The two classes were taught separately, but there was some communication between classes which resulted in both classes concentrating on the same projects. Questions such as "What projects are the other students choosing?" were common.

During the nine weeks of the personalized program, twelve of the fifty-three students tried more than three projects. The most projects tried by one student was six. Students tended to change from unpopular (in their class) to popular projects quickly and to continue with popular projects for several weeks.

As shown in Table 2, projects chosen by boys were different from those chosen by girls. Almost every boy worked with Airplanes at one time or another and several boys worked on this project for the whole personalized period. Every girl worked on Acid-Base and many girls worked on Candles and Dissolving. Only one girl tried Airplanes and only one boy tried Candles. Acid-Base was tried by thirteen boys compared to twenty-three girls.

Student reports. One class developed a form for writing reports (Figure 1), in the other class each child used his own format. The number of reports written by the students varied from one to nine. Most students only wrote reports in order to change activities; few students appeared to keep records because they wanted to find something out.

Several students developed quite sophisticated methods of recording data from their experiments. For the Acid-Base experiments, for example, students made tables of various liquids and their reactions to certain indicators. These recording methods were then adopted by other students. Thus, similar patterns of recording results were frequently used by students working with the same equipment.

Student reports were analyzed by categorizing performance on Naming Objectives and Describing Procedures. The categories used and the number of reports falling into each category are given in Table 3. Twelve students are responsible for all the reports in categories 4, 5, and 6 for Describing Procedures and in category 4 for Naming Objectives. Thus, 75 percent of the students did not formulate objectives on a formal level, did not perform sequential steps, did not control variables, and did not draw conclusions. In the most common type of report, the student named some variables and

applied a method of measurement while experimenting. Only four students consistently wrote reports at the same level of sophistication. Because there were so few guidelines for doing experiments and writing reports, we do not know whether students were unable or unwilling to report on controlled experiments in this setting. Observers noted that more controlled experimentation took place in the classroom than was reflected in the reports.

Staff members. Students frequently sought out the staff members present in the classroom. Besides answering the many questions posed by the students, staff members collected reports, supplied new materials or replenished materials in projects that were underway (e.g., provided more candles, acids, bases, or indicators), and helped with experiments. Questions regarding what kinds of experiments to do next, how to record data, and how to write reports were frequently asked.

Observations of staff members. Observers regularly wrote reports about what was happening in the personalized program. The major observations were as follows:

1. Student use of equipment was primarily exploratory. Perhaps because the equipment was unfamiliar, students tended to use a concrete approach and investigate variables unsystematically.

2. This type of activity (equipment but no specific directions) did not provide a focus for the student. Thus, students appeared unable to think ahead, to plan experiments, or to design controlled investigations under these conditions.

3. With each student working on his own activity, both the number of students in the class (26) and the available space, caused congestion. Although a large multipurpose room and the playground (during good weather) were used, crowding was still a problem.

4. The 45 minute time space was reasonably successful although slightly more time would have been better for some projects. A more flexible time arrangement would be more appropriate for this type of program.

5. Storage of equipment is a problem in the classroom. The boxes for individual projects took up a large space. Shelves for replacement items were also necessary. Due to space limitations, these shelves were not in the classroom, and the leader spent part of each session transporting equipment.

6. Students, at least in the 9 weeks of this program, were not able to suggest activities without some help from a knowledgeable adult. Student interest was easier to satisfy by providing many choices than by asking for suggestions.

7. Students frequently consulted adults about their work. Although the program was personalized, students did not work autonomously. Adult approval was a major part of the reward structure in the classroom and was sought frequently during the personalized program.

8. It appeared that there was a well established social structure among the students. Thus, students were influenced by their peers in their choices of activities and their procedures for doing activities.

9. Student interest tended to rise when a new activity became popular in the class and subside after the activity had been in use for several weeks. In contrast, during the introduction to experimentation, student interest was more constant. Although never as high as the peak for the personalized program, student interest was reasonable for a group program.

Scores on Evaluation Measures

Results for the Science Process Test (SPT) and the Controlling Variables Interview are given in Table 4. Although the three forms of the SPT were designed to be parallel tests, scores for controls varied somewhat from one form to the next. Either controls became familiar with the questions and performed better on Form 3, or Form 3 was easier than the others. Since scores for controls differ from one form of the SPT to the next, comparisons will be made only between controls and experimentals at each testing, not between scores from one form of the test to the next. Since the standard deviations for experimentals and controls on each test were not homogeneous, the *t*-test with the Satterwaite correction for unequal variances was used to assess differences between groups.

As can been seen in Table 4, for the Post Introduction Test, experimentals performed significantly better than controls on the Variables section of the SPT; experimentals were significantly better than controls on all posttest measures. Experimentals had slightly but not significantly higher scores than controls on SPT Experimentation and Controlling Variables Interview (Post Introduction Test), so significant posttest differences on these measures must be attributed to the combination of introduction and personalized program.

Examination of scores for individual items of the SPT experimentation posttest revealed that experimentals outscored controls on questions about critizing experiments and explaining compensating variables but performed similarly to controls on the question about setting up experiments.

Results for the Controlling Variables Interview, as shown in Table 4, further substantiated the findings for the SPT Experimentation

subtest. Experimentals performed slightly better than controls on the Post Introduction Test and significantly better than controls on the Posttest. Thus, the introduction and personalized program succeeded in teaching experimentals to significantly exceed controls in ability to recognize and describe variables and in ability to control variables when criticizing experiments, describing experiments, or explaining compensating variables. These results reinforce our current research premise that a combination of a group laboratory centered program and personalization is an effective means of presenting science in the elementary school.

Individual Differences

Reliability. While high reliability for evaluation measures is not critical for comparing groups, it is relevant to any analysis of individual differences. The median Test-Retest reliability for the parallel forms of the SPT given to controls was .26. This is quite low, therefore, these measures were not used by themselves to assess differences between individuals. The Test-Retest reliability for the Controlling Variables Interview was .68 which, with 24 subjects, is quite high.

Standard deviations. As mentioned above, the standard deviations for experimentals and controls were not homogeneous. On the variables subtest of the SPT, experimentals had consistently higher standard deviations. This was due to one experimental student who consistently scored 10 points higher than any other subject. On the experimentation subtest of the SPT, the experimental and control standard deviations were equivalent on all but the Posttest. One would expect a group program to reduce the standard deviation; thus, the significantly greater standard deviation for experimentals than for controls on the posttest indicates that the program may have increased individual differences.

Relationship between performance and ability. Since there was a larger standard deviation for experimentals than for controls on the posttest, we investigated the relationship between posttest performance and scores on achievement tests. Scatter plots of the relationship between achievement and performance on the post-introduction test and the posttest are shown in Figure 3. As can be seen, there are no differences between the experimental and control scatterplots for the post-introduction test.

In the posttest, some experimentals who had low achievement scores had high posttest scores, yet no controls with low achievement scores had high posttest scores. Thus, it appears that the personalized program was especially effective for low achievement students.

Summary and Conclusions

A personalized science program preceeded by an introduction to experimentation was provided for two fifth-grade classes in an upper middle class school. Two other classes served as controls. The program reflected reported results of the English individualized science programs, the philosophy of Piaget, research on aptitude treatment interactions, and our own experience with laboratory science programs.

Observations during the program revealed that the social structure of the classroom, and the fact that most rewards in the usual classroom came from the teacher, influenced the behavior of the students. The activities, which consisted of equipment chosen by the students but no directions, led to exploration of the equipment instead of experimentation planned by the students. Finally the organization of a personalized science program presented problems in a traditional

classroom (e.g., storage of equipment, involvement of all members of a class for the same length of time, dispensing of materials to large numbers of students).

Evaluation of student progress in describing variables and experimentation showed advantages for the program. Experimental students were significantly better than controls in describing variables after the Introduction and after the personalized program. Experimentals exceeded controls in their understanding of experimentation after the Introduction and personalized program.

Essentially, it appeared that classes unaccustomed to working alone find the transition from group to personalized work difficult. One way to ease this transition would be to provide an introduction on how to work alone. A primary purpose of such an introduction would be to establish a method for rewarding working alone. Further research is needed to determine if this would be effective.

It was clear that students in the experimental classes had difficulty working autonomously on open ended projects. The Plowden report on English schools indicates that children in "open" schools frequently work autonomously (Central Advisory Council for Education, 1967). This is perhaps the major reason that in English personalized science programs there is little peer influence. (Actually some educators have criticized individualized programs because they do not provide opportunities for peer interaction. From our limited experience it seems that students will interact even if this is not encouraged). One way to encourage autonomy in a personalized program would be to provide directions for each activity so that students would not be required to make their own decisions about how to proceed. This is a question for further research.

It has been proposed that logical thinking can be improved in children by letting them work with equipment or "mess about" in science (Hawkins, 1965).

Since students made progress in this program, one could interpret the results as supporting the idea that children develop ideas from simply working with equipment. Results and observations from our research indicate that the introduction to experimentation played a vital role in focusing the children's attention. The introduction provided students with techniques for using equipment and manipulating variables. This contributed to their approach to carrying out experiments.

We are currently investigating ideas about personalized science which have grown out of this research. In order to assist students in choosing projects we have developed a large number of possible activities for a personalized science center. We have also changed the format of our activities such that the student's initial work with a particular project is somewhat structured. In our new format the student chooses a particular "challenge" such as "Find out which glue is best." He can then get materials and directions for solving the challenge. When he solves this challenge a new challenge is offered, related to the previous one, but no directions are given. Using this new format we are investigating the effectiveness of groups smaller than a whole class and we are comparing a peer teaching situation with an autonomous situation.

Table 1. Activities Suggested by Students and Presented at "Project Preview"

Activities Suggested by Students	Number of Times Suggested	Activities Presented at "Preview"	Number of Times Chosen at "Preview"
Physical Science			
Color Changes	19	Thermicon cards	Given to everyone to enjoy
		Color Wheels	9
Chemicals	19	Acid-Base Indicators	7
Power/Energy	12	Batteries, Bulbs, and Motors	2
		Magnetic Oscillator	
		Electromagnet	2
		Magnetic Quadrant	6
Aeronautics	4	Rubber Powered Airplanes	5
Microscopes	3	Geometric Optics	10
		Shadow Box	
		Pinhole Camera	
Filtering and Distillation	3	Dissolving Sodium Thiosulfate and Magnesium Sulfate	3
Geology	2	This was not a first choice of any student	
Whirly Birds	2	Hot Wheels	
Army Tank	1	Strength of Human Hair	2
Hot Wheels	1		
Time	2	Water Clocks and Sand Clocks	
Smoke Bomb	1	Rate of Candle Burning	1
Air	1	Stringed Instruments	
Make Paper	1	Strength of Wood	
Electric Car	1	Hot Wheels and Motors	1
Remote Airplane	1	Child's own Remote Airplane	1
Oil Spill	1	Oil Spill	1
Life Science			
Animals and Nature	10	*	
Dissecting	7	*	
Plants	5	*	
Aquariums	2	*	
Chameleons	2	*	

*No life science activities were used, see text for explanation.

Table 2. Activities Used During Personalized Program

Activities Presented at "Project Preview" or Provided by Special Request	Number of Students Who Used the Activity during the Personalized Program				
	Boys	Girls	Class 1	Class 2	Total
1. Color Wheels	1	8	3	6	9
2. Acid-Base Indicators	13	23	15	21	36
3. Batteries, Bulbs, and Motors	1	2	2	1	3
4. Magnetic Oscillator	0	0	0	0	0
5. Electromagnet	1	1	1	1	2
6. Magnetic Quadrant	6	0	4	2	6
7. Rubber Powered Airplanes	22	1	10	13	23
8. Geometric Optics	1	11	4	8	12
9. Shadow Box	0	6	2	4	6
10. Pinhole Camera	0	0	0	0	0
11. Dissolving Sodium Thiosulfate	2	13	9	6	15
12. Hot Wheels	0	0	0	0	0
13. Strength of Human Hair	0	2	2	0	2
14. Water Clocks and Sand Clocks	0	0	0	0	0
15. Rate of Candle Burning	1	19	11	9	20
16. Stringed Instruments	0	0	0	0	0
17. Strength of Wood	0	0	0	0	0
18. Hot Wheels and Motors	1	0	0	1	1
19. Child's Own Remote Airplane	1	0	1	0	1
20. Oil Spill	2	0	2	0	2
21. Sliders	0	1	1	0	1
22. Stopper Poppers	2	0	0	2	2
23. Flip Books	1	1	0	2	2
Total	55	88	67	76	143

Table 3. Categorization of the 146 Reports Made by 53 Experimental Subjects for Naming Objectives and Describing Procedures

Category	No. of Reports	Percentage of Total Reports	No. of subjects Who Made Reports
Naming Objectives			
1. No objective stated	58	.40	23
2. Concrete objectives stated in general terms (e.g., "Want to mix liquid to make lovely color")	33	.23	20
3. Concrete objective stated in specific terms (e.g., "How much weight can the hair hold")	54	.36	28
4. Formal objective or hypothesis (e.g., Find the relationship between magnets and metals)	1	.01	1
Describing Procedures			
1. No description	29	.20	
2. Variables listed quantitatively (e.g., the amount of water)	37	.25	21
3. Some quantity is measured (e.g., two drops of BTB)	44	.30	24
4. One or more variables are controlled(e.g., put same amount of BTB in each one)	9	.06	6
5. Conclusion is drawn from experiment (e.g., acid turns BTB yellow)	16	.11	10
6. One or more sequential steps ("if-then" relationships are described; e.g., acid turns BTB yellow, then you can add a base and turn it blue again)	11	.08	6

Table 4 Results of Pretest, Post Introduction Test, and Posttest for Controls (N = 51) and Experimentals (N = 52)

Evaluation Measure	Pretest				Post Introduction Test				Posttest			
	Control		Experimental		Control		Experimental		Control		Experimental	
	$\bar{m}$	SD	$\bar{m}$	SD	$\bar{m}$	SD	$\bar{m}$	SD	$\bar{m}$	SD	$\bar{m}$	SD
Science Process Test (SPT)												
Variables	3.2	2.1	3.9	4.1	2.8	2.9	7.9**	5.9	3.9	3.6	6.4**	4.2
Experimentation	5.2	2.9	4.7	2.6	4.7	2.4	5.4	2.5	5.7	2.3	7.4**	3.2
Controlling Variables												
Interview[1]					1.8	1.7	2.3	1.9	1.7	1.5	2.7**	1.7

**p1. 01

[1]No pretest given, see text, N for post introduction test = 27

Figure 1. Sutdent Report Form

NAME _____ DATE _____

Title of Experiment:

Description of experiment: (What you are going to do.)

Variables:

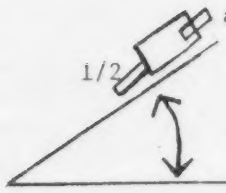
What you changed. How you changed it:

Results:

Figure 2. Student Process Test Form 3

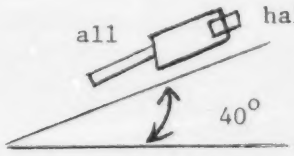
NAME _____

STOPPER POPPERS



A. _____ _____

desk



B. _____

floor

Part I. You have just seen an experiment. Make a list of all the variables (all the things) which influence how far the stopper will go.

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

_____

NAME_____

Part II. Suppose you had this weight that you could tape on the stopper. Now, how would you set up an experiment to find out what effect this weight has on how far the stopper goes?

_____

_____

Make a drawing of your experiment. Label each thing in your drawing.

Describe your experiment. Tell the order of the things you would do.

_____

_____

_____

_____

_____

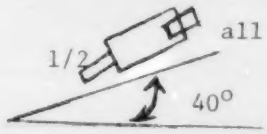
_____

_____

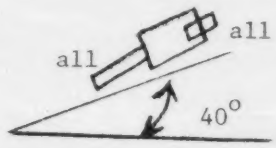
NAME_____

Part III

1. Here is an experiment to find out if how far out the plunger is makes a difference in how far the stopper goes.



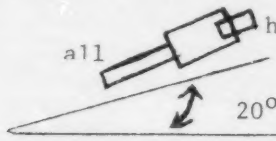
floor



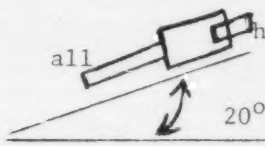
desk

Is there anything wrong with this experiment?_____Explain your answer.

2. Here is an experiment to find out if how far the stopper is pushed in makes a difference in how far the stopper goes.



floor



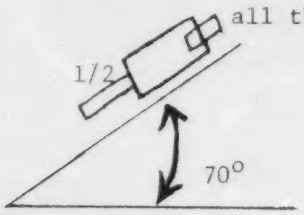
floor

Is there anything wrong with this experiment?_____Explain your answer.

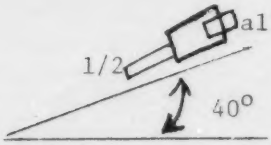
NAME_____

Part III (continued)

3. Here is an experiment to find out if where you launch the stopper from makes a difference in how far the stopper goes.



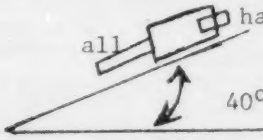
desk



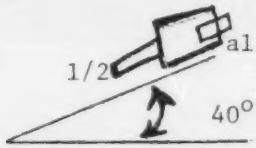
floor

Is there anything wrong with this experiment?_____Explain your answer.

4. Here is an experiment that we did.



floor



floor

We released each stopper the same way and the stoppers went the same distance each time. How would you explain that?

Figure 3a

Scatterplot of Control Group Science Process Test, Post Introduction Scores and Achievement Test Scores, N = 52

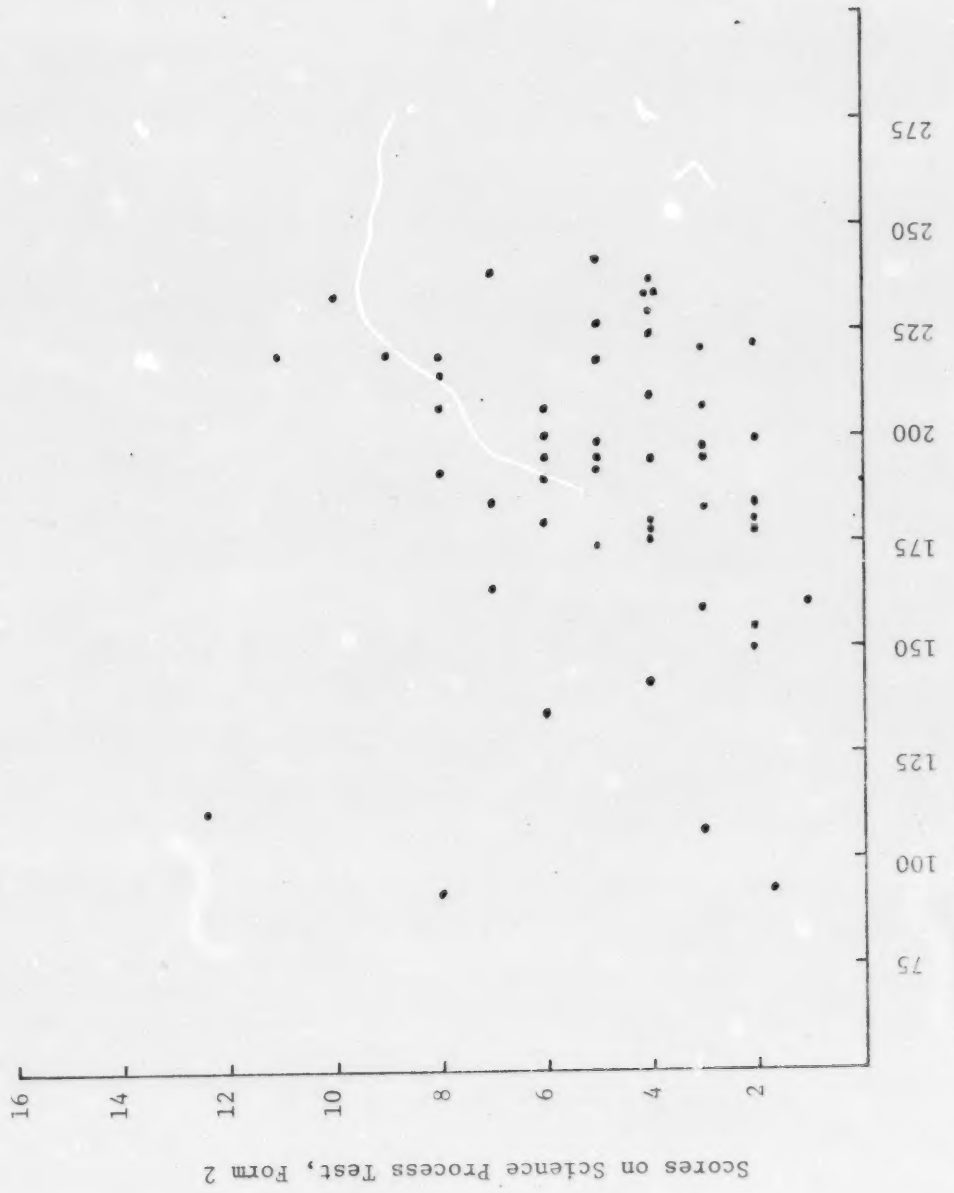
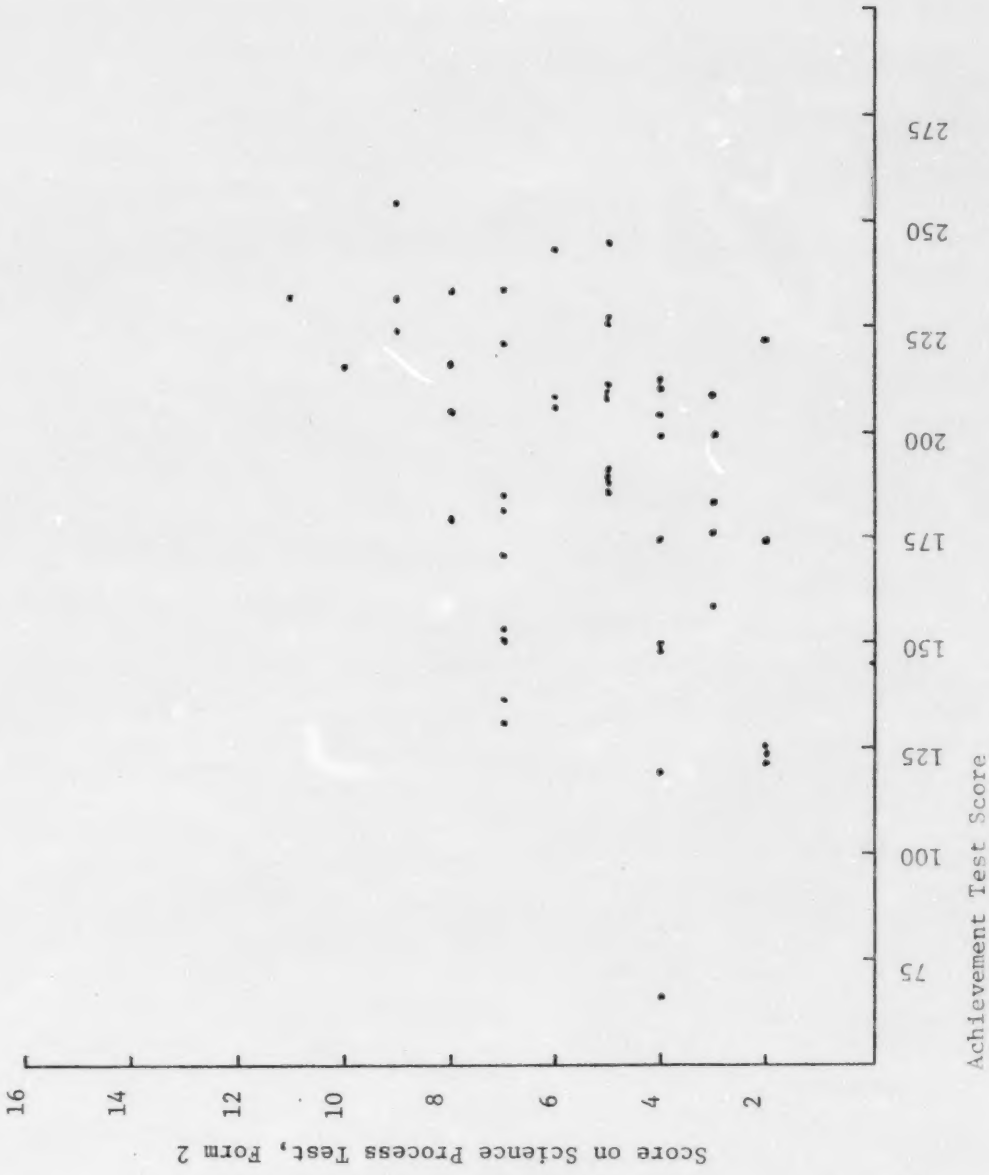


Figure 3b

Scatterplot of Experimental Group Science Process Test, Science Process Test, Post Introduction Scores and Achievement Test Scores N = 50



Scatterplot of Control Group Science Process Test Posttest Scores and Achievement Test Scores, N = 51

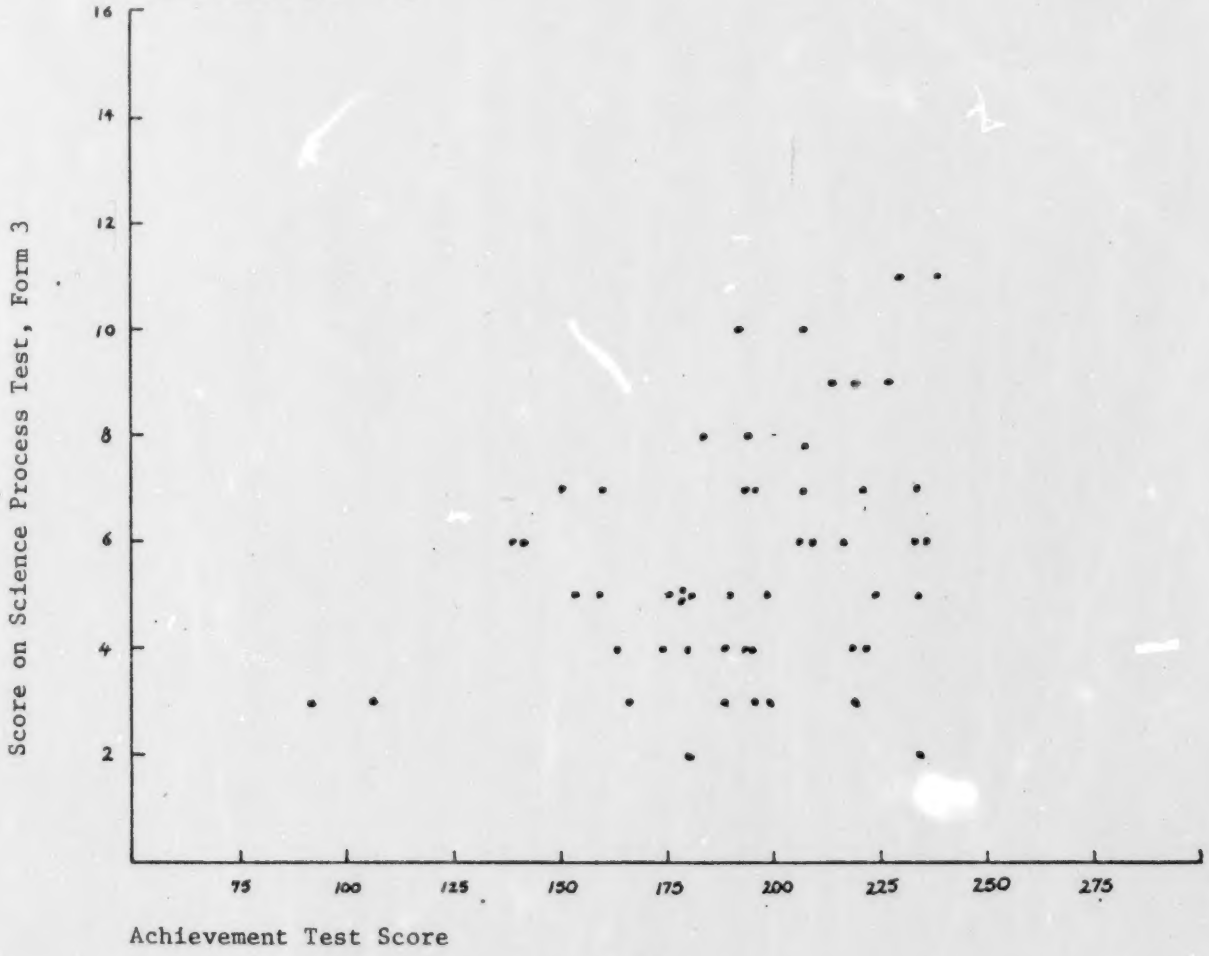
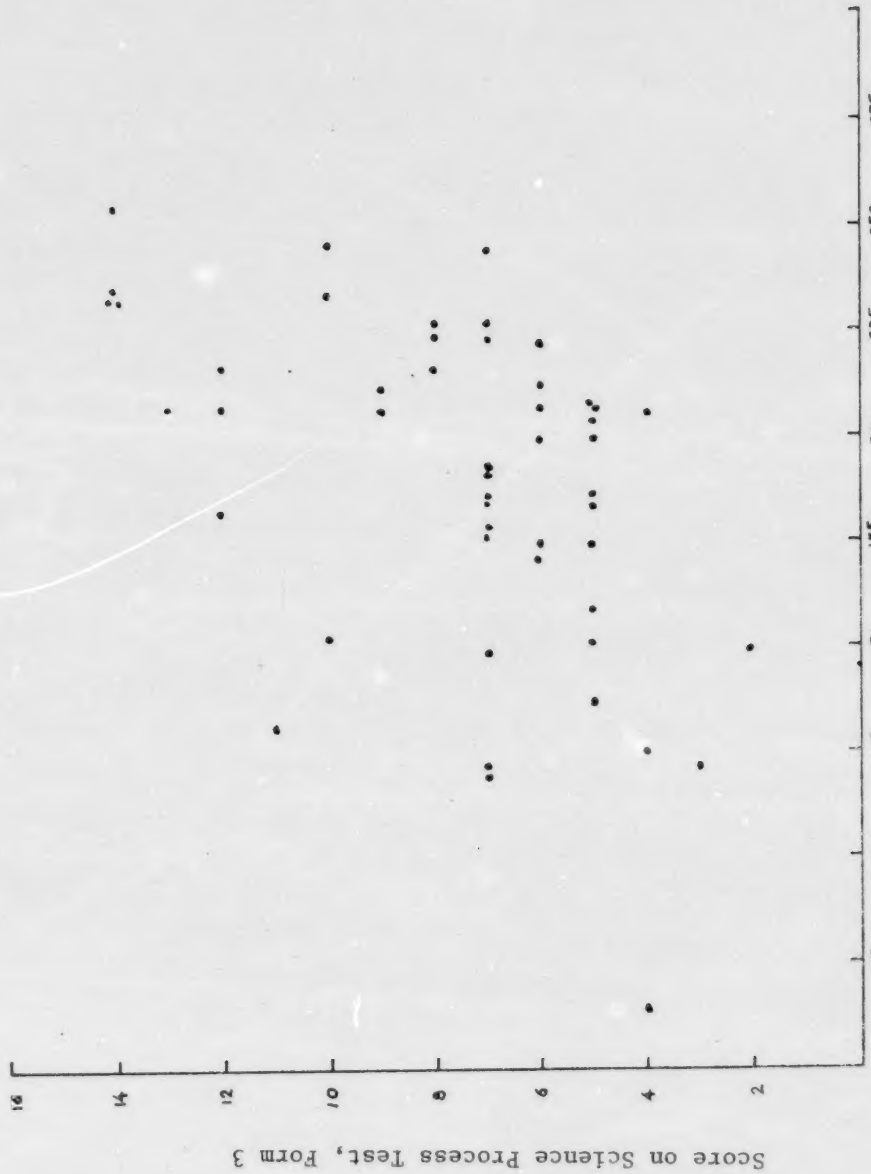


Figure 3c

Figure 3d

Scatterplot of Experimental Group Science Process Test, Posttest Scores and Achievement Test Scores, N = 51



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